CHAPTER 7

TRANSFORMERS AND REGULATORS

Section I-CONSIDERATIONS

7-1. Voltage provisions covered.

This chapter provides maintenance and repair requirements for transformers used in the transmission and distribution of electrical energy and for voltage regulators. Requirements apply to units having at least one medium-voltage winding and generally providing three-phase service, although single-phase units may be found for housing or other small loads.

7-2. Defining transformer and regulator characteristics.

A transformer utilizes electromagnetic induction between circuits of the same frequency, usually with changed values of voltage and current. All transformers covered in this chapter are constant-voltage type. That is, they maintain an approximately constant voltage ratio over loads from zero to the rated output. Constant-current transformers are described in chapter 6, section IV Transformers can be classified in various ways, but their basic construction consists of windings, magnetic cores on which windings are coiled, insulation, and any special connections applying to the type of load.

a. Winding terminology. Winding terminology given below is based on the voltage flow, rating, or winding provisions.

(1) A primary winding has input from the power source and a secondary winding supplies input to the loads.

(2) A high-tension winding has a higher voltage than a low-tension winding. Most transformers have high-tension primary windings and are therefore step-down transformers. If the same transformer utilized the low-tension winding as the primary winding it would be a step-up transformer.

(3) Most transformers have two windings, which are electrically insulated from each other. High-voltage power transformers found in transmission-to-distribution substations may have a single winding (autotransformers) or a tertiary winding to eliminate voltage problems and/or to supply a second load voltage economically.

b. Regulation. Transformers can maintain an acceptable voltage ratio of about a 2 percent voltage drop from zero to rated output in most cases. Most distribution transformers and smaller power transformers have tapped windings, which permit adjusting the output voltage to broaden the range of primary voltage inputs. The transformer will have a manual tap changer, which can be operated if the transformer is de-energized. However, on substations which serve varying loads, such as pumping facilities, or on large installations with long primary feeder lines, taps may not provide sufficient voltage regulation and other means are necessary.

(1) *Load-tap-changing (LTC).* This feature installed on a transformer provides automatic tap changing under load, and normally varies the voltage to plus or minus 10 percent of the system's rated voltage by changing tap connections using a motor-driven, tap-changing switch.

(2) Voltage regulators. Sometimes voltage regulation is needed and the system transformers do not include the LTC feature. Voltage regulators are used to supply the control for the variations in load. A voltage regulator needs similar servicing to that required for a power transformer. A step-voltage regulator operates on the same principal as the LTC mechanism. An induction voltage regulator has a series winding and a shunt winding, and uses a motor to rotate the shunt winding to either add to (boost) or subtract from (buck) the series winding voltage. The action provided is dependent upon the voltage induced in the series winding and the respective polarities of each winding (that is, the respective instantaneous directions of currents entering the primary and leaving the secondary terminals during most of each half cycle). The switching mechanism in most new voltage regulators is practically maintenance free, but many of the older units require considerable servicing. The manufacturer's recommendations should be followed for all maintenance and servicing requirements.

7-3. Transformer classification.

Transformers are generally classified by size, insulation, and location.

a. Size. Transformers rated above 500 kVA are classed as power transformers. Transformers rated at 500 kVA or less are classed as distribution transformers, as they usually have low-tension windings of less than 600 volts. Instrument transformers, covered in chapter 3, section VI, are not considered distribution transformers since they do not serve utilization loads.

b. Insulation. There are two types of insulating classifications recognized by ANSI/IEEE C57.12.80.

Insulation classifications are affected by the insulation's temperature rating and by the method of cooling needed to remove the heat from the transformer.

(1) *Liquid-immersed transformers.* The core and the coils are immersed in an insulating liquid. A flammable mineral oii insulation is the most frequently used liquid. Various less flammable liquids are used to meet NEC code requirements. Only flammable and less flammable liquids are acceptable on military installations. Nonflammable-insulated liquids, though available, are not considered environmentally acceptable. Polychlorinated biphenyl (PCB) insulated transformers should have been removed to meet OSHA requirements. Replacement of liquid-filled transformers in or near buildings must take into account the latest applicable NEC code restrictions, which might require an existing installation to be modified or a different type of insulation to be provided.

(2) *Dry-type transformers.* The core and coil are in a gaseous or dry-compound insulating material.

c. Cooling classes. Distribution and small power transformers are generally self-cooled. Other methods of cooling may be added to provide a greater load capacity than would be available with a self-cooled unit. Cooling methods include forced air-cooling (fans) for liquid-immersed and dry-type units; and forced air-cooling and/or forced liquid-cooling for liquid-immersed transformers. Dry-type units can be ventilated, nonventilated, or sealed. Transformers may be provided with the cooling equipment, may have provisions for adding cooling equipment, or may be without future capability for adding cooling equipment.

d. Insulation temperature ranges. Transformers are designed to carry their normal rated load in specific ambient temperatures with a maximum stated temperature rise for normal life. If ambients or temperature rises are exceeded under operating conditions, the transformer life may be decreased. If lower temperatures occur, the transformer life may actually be increased. Overload capabilities of transformers are indicated in ANSI/IEEE C57.91, ANSI/IEEE C57.92, and ANSI/IEEE C57.96.

(1) *Ambient temperatures.* The ambient temperature for an air-cooled unit should not exceed 40 degrees C; and the average temperature for any 24-hour period should not exceed 30 degrees C; with a minimum ambient temperature for dry-type units of not less than minus 30 degree C. These restrictions apply if the transformer is to provide its normal life expectancy.

(2) *Insulation temperature ratings.* Liquid-immersed transformers are rated 65 degree C rise or 55/65 degree C rise. Dry-type transformers are rated 150 degree C rise, 115/150 degree *C* rise, or 80/115 degree C rise. The lower the temperature rise the lower the rated full-load capacity.

(3) *Altitude.* The dielectric strength of transformers, which depend in whole or in part upon air for insulation, decreases as the altitude increases due to the effect of decreased air density. This applies to liquid-immersed transformers as well as dry-type transformers.

e. Location. Transformers can be classified by their location, but only those which are most often installed on military facilities are covered below.

(1) *Outdoor transformer.* This is a transformer of weather-resistant construction, suitable for service without additional protection from the weather. Industry standards also classify transformers as indoor units, which must be protected from the weather.

(2) *Pole-type transformer.* An outdoor transformer which is suitable for mounting on a pole or a similar structure.

(3) *Pad-mounted transformer.* This is a unitized or compartmental-type transformer, with enclosed compartments for medium-voltage and low-voltage cables entering from below, and is mounted on a pad. The terminology is confusing, and it is recommended that this type of unit be called a pad-mounted compartmental-type transformer.

(4) *Station-type transformer.* A unit designed for mounting on a pad and installed in a substation, more often referred to as a substation type.

(5) *Unit substation transformer.* A unit which is mechanically and electrically connected to, and co-ordinated in design with, one or more primary or secondary switchgear lineups or a motor-control center. A primary unit substation has a medium-voltage secondary. A secondary unit substation has a low-voltage secondary.

(6) *Other types.* These include submersible, subway, vault-type, network, sub-surface, and direct-buried units.

Section II-MAINTENANCE

7-4. Transformer inspection and maintenance frequencies.

Transformers are simple rugged devices which will give many years of trouble-free operation if provided with periodic inspections and maintenance. Inspections of transformers should be made regularly and permanent records kept of all observations and tests for both scheduled and unscheduled inspections. The frequency of inspection should be based on the importance of the transformer, the operating environment, and the severity of the loading conditions. In addition to the inspection recommendations listed herein, it is good practice to develop a habit of visual inspection whenever a transformer area is visited. In this way leaks, cracked insulators, loose connections, and similar problems may be noticed before serious problems develop that might affect the continuity of service. When working around a transformer, particular care must be taken in handling all tools and other loose articles, since material dropped into the windings and allowed to remain can cause a breakdown.

a. Power transformers. For maintenance purposes consider the impact that the loss of a power transformer will have on the facilities operation. Utility-facility interconnection transformers and transformers with medium-voltage secondary lines can be defined as significant impact transformers, while other power transformers can be considered as less significant impact transformers. There may be slightly different maintenance techniques for liquid and dry-type transformers, but the general approach is the same.

(1) *Significant impact transformers.* Table 7-l is a recommended inspection and maintenance checklist based on input from NFPA, NETA, and manufacturer's published guides. For transformers having a less significant impact, checking should be decreased as covered later.

(2) *Less significant impact transformers.* Transformer readings should include load current at peak load, voltage readings during both peak-load and low-load periods, temperature, liquid level, and pressure/vacuum recordings. These readings should be taken not less than every 6 months along with general inspection tests from table 7-l that are not annual or 3-to-6 year tests. Other tests of table 7-l may be needed dependent upon the results of the 6-months' tests.

b. Distribution transformers. Porcelain bushings should be kept clean and the transformers inspected annually. Check for broken porcelain, loose power connections, blown fuses, and defective surge arresters. Check for leaks, hardened bushing gaskets, corroded or broken ground connections, rusting of tanks, and signs of corrosion on terminals, bushing studs, and connectors. If the transformer is excessively noisy or has a ruptured gasket, then the unit should be opened, internally inspected, and tested.

(1) *Load test.* A load test should be made annually on transformers which supply a load that is known to be increasing. Transformers which supply a steady connected load should be load tested every 5 years. Load tests should be made with portable ammeters (dial-indicating or recording-chart type), installed for at least 24 hours on a peak loading period day as determined by spot checking with a clamp-on ammeter. Reasonable accuracy and complete safety should be of the greatest importance in making transformer load surveys. Readings should be taken on the secondary side of the transformer whenever possible. Testing all transformers may not be necessary, because similar areas and buildings may have quite similar loads.

Table 7-l. Transformer inspection and maintenance checklist

General inspection items	Frequency
Load current	Weekly or monthly
Voltage	Weekly or monthly
Temperature	Weekly or monthly
Liquid level or pressure vacuum	Weekly or monthly
Protective devices	Annually
Protective alarms	Monthly
Ground connections	Every 6 months
Surge arresters	Every 6 months
Pressure-relief devices	Every 3 months
Breather	Monthly
Auxiliary equipment and bushings	Annually
Load tap changer (LTC)	Annually
External inspection	Every 6 months
Internal Inspection	From 3 to 6 years
Solid insulation (winding)	
Insulation resistance	Annually
Polarization index (PI)	Annually
Power factor	From 3 to 6 years
Hi-pot (ac or dc)	From 3 to 6 years
Induced potential	From 3 to 6 years
Transformer turns ratio	Annually
Insulating liquid	
Gas analysis	Annually
Dielectric strength	Annually
Color	Annually
Acidity (neutralization number)	Annually
Interfacial tension (IFT)	From 3 to 6 years
General inspection items	Frequency
Power factor test	From 3 to 6 years

(2) *Dielectric tests.* Dielectric tests of liquid-immersed transformers need not be made on distribution transformers of less than l00-kVA capacity. Liquid samples should be taken at 5-year intervals from each liquid-immersed distribution transformer of 100-kVA and greater capacity. These samples should be given a dielectric test. If a liquid-immersed transformer has been out of service for one year or more, dielectrically test a liquid sample from that unit before re-energizing the transformer. When a liquid sample fails to meet the dielectric standard, filter the liquid until it meets the standard or replace with new liquid of a type and grade recommended by the transformer manufacturer.

7-5. Transformer inspections.

Inspection and repair will vary dependent upon the type of transformer installed. Always expand or modify these general directions in accordance with the manufacturer's recommendations.

a. Readings. Current, voltage, and temperature readings should be taken at the peak load time. Voltage and liquid level readings should be taken at the end of a low load period.

(1) *Current.* Load currents are a very important part of recommended regular inspections. If the observed current in any phase exceeds the rated full load value, and the rated maximum temperature is exceeded, steps should be taken to reduce the load. Trends in load currents should be noted for programming additional transformer capacity or consolidation of loads on lightly loaded transformers.

(2) *Voltage.* Overvoltages and undervoltages can be detrimental to the transformer and the load it serves. Investigate immediately and take corrective action to bring the voltage within acceptable limits.

(3) *Temperature.* Use integral unit-mounted temperature gauges and maximum temperature indicators, where available. Record readings, and reset the maximum temperature indicator. Excessive temperature can indicate an overload interference with the normal means of cooling. Prolonged operation at an overtemperature will accelerate liquid deterioration; result in a reduced life expectancy of the solid insulation; and may greatly increase the risk of failure. Constant monitoring against overtemperature is often provided by special alarm contacts on a transformer's temperature gauge.

(4) *Liquid level.* Check regularly, and especially after a long low-load period with a low ambient temperature, as this is when the liquid level should be at its lowest point. Liquid must be added before the level falls below the sight glass or bottom reading of the liquid-level indicator. If there is no liquid-level indicator, de-energize the transformer and check the liquid level by removing the inspection plate on the top of the transformer, or by removing the top if no inspection plate is available.

(5) *Pressure / vacuum.* Pressure/vacuum gauges are commonly found on sealed-type transformers. They indicate the integrity of the sealed construction and should be added to transformers without them, if feasible. The readings should be compared to the recommendations of the manufacturer pertaining to normal operating ranges. High pressures indicate an overload or internal trouble and a sustained zero pressure reading indicates a leak or a defective gauge.

(6) *Miscellaneous.* The features of special types of transformer construction that should be included in regular inspections include:

(a) The water-in and water-out temperatures of water-cooled transformers.

(b) The oil-in and oil-out temperatures of forced-oil-cooled transformers with oil-to-air or oil-to-water heat exchangers.

(c) The pressure in the nitrogen cylinder for a transformer equipped with an automatic gas-pressure system. If the pressure drops below the manufacturer's recommended value, the cylinder should be replaced and leaks repaired.

(d) Dehydrating breathers should be checked to ensure that they are free from restriction and have not absorbed excessive moisture.

(e) For dry-type transformers, the operation of integral ventilating fans should be checked. If installed indoors, the temperature of the room should be measured regularly and recorded. Proper ventilation is essential, and any material or obstruction that might prevent the free circulation of air around a transformer should be removed. If the room has power-driven ventilating fans, their correct operation should be determined. Overtemperature alarms, if provided, should be tested. Excessive air velocity can be as damaging as no circulation at all.

b. Inspections and repairs. The inspection and repair recommendations given are general in nature. For specific directions, the manufacturer's recommendations should be followed.

(1) *Protective devices.* Basic transformer protection is required by the NEC and is often supplemented with additional protective relays and devices. Inspect and maintain these devices on a regular basis to ensure that they will operate in case of failure. Provide an annual maintenance check for sudden pressure relays, undervoltage and overvoltage relays, alarm and auxiliary relays, and wiring and instrument transformers associated with the protective relays.

(2) *Protective alarms.* Transformers come with various types of alarms, such as overtemperature, liquid temperature, and pressure-relief devices. These devices usually have open-type contacts connected to either alarm or to trip the protective circuit breaker. Because of their importance, check alarm contacts and associated wiring on a monthly basis.

(3) *Ground connections.* A transformer tank is normally provided with a ground connection to eliminate electric shock (however, at least one state's safety orders do not permit pole-mounted transformers to have grounded tanks). The ground resistance of a substation may vary from less than 1 ohm for very large capacity substations, to 25 ohms

for very small capacity substations. The importance of the substation determines the need for ground resistance tests.

(4) *Surge arresters.* Surge arresters are used to protect aerially supplied transformers from lightning and other surges. They should be inspected for looseness, broken parts, dirt, and other deposits. Clean, tighten, and replace parts as necessary annually.

(5) *Pressure-relief devices:* Most transformers are equipped with pressure-relief devices to relieve excessive pressure in the tank due to internal arcing. This device is set to open at a pressure of 10 to 15 pounds per square inch (69 to 103 kilopascals). A quarterly inspection of pressure-relief devices should include checking for leaks around joints, diaphragm cracking, and the like. A cracked or leaking diaphragm should be replaced at once.

(6) *Breathers.* Many large transformers have breathers of either the open type or dehydrating type. The function of the dehydrating agent is to prevent moisture from entering the transformer tank. Most dehydrating breathers contain silica gel, which will change from blue, when dry, to pale pink when wet. Inspection can be made through a glass window provided for that purpose. The breathers should be checked monthly and the dehydrating agent should be replaced or reconditioned if it is found they restrict breathing or are wet.

(7) *Auxiliary equipment.* Auxiliary equipment required for cooling, such as fans, oil pumps, control devices, and wiring, should be checked on an annual basis. The equipment should be cleaned and damaged parts replaced.

(8) *Load tap changers.* Load ‘tap changers should be thoroughly inspected and the insulating oil tested at the end of the first year’s operation. Subsequent annual inspections should include testing of the insulating oil based on the number of operations, the condition of the oil, and the condition of the contacts. Maintenance of the mechanism will vary with the type and manufacturer. The manufacturer’s recommendations should be followed.

(9) *Visual inspection safety measures.* If a transformer is given an external visual examination, the case of the transformer should be regarded as energized until the tank ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, de-energize the transformer, using an approved positive lockout or tagout procedure to ensure against an unplanned reenergization and resulting hazard to personnel or equipment. Before doing anything else, test to ensure that the equipment is de-energized, and ground the equipment prior to the start of any work.

(10) *External inspection.* Provide an external inspection on a semi-annual basis. Check the tank, radiators, the tap changer, and all gasketed or other openings for leaks, deposits of dirt, or corrosion. Inspect connections for signs of overheating and corrosion. Inspect bushing insulating surfaces for tracking, cracks, or chipped skirts. Inspect bushing gasketed bases for leaks. Leak repair, cleaning, and painting should be done as required. See chapter 3, section VII for bushing maintenance. Check louvers in the enclosures of ventilated dry-type transformers for clogging by dirt or other obstructions. A high noise level or change in the noise level could indicate improper installation, loose windings, or misaligned barriers.

(11) *Internal inspection of liquid-immersed transformers.* On an open-type liquid- immersed transformer, the look-in port cover can be removed to examine for evidence of moisture or rust around the bushing supports and transformer top cover. To examine the tank and core, the liquid can be drained out. Examination of the core should be made to check for sludge deposits, loose connections, and any damage to the transformer parts. Evidence of carbon may indicate internal problems. Windings should be checked for damage to terminal panels, barriers, and loose connections. The need to untank a transformer for internal inspection should depend on the age of the transformer and its overloading and/or trouble history. The frequency of this inspection should be 5 to 10 years or more.

(a) Contamination. Contamination or impairment of the insulating liquid during examination should be carefully avoided. If the humidity is high, exposure should be avoided entirely, unless the work is absolutely necessary and cannot be postponed, in which case special humidity-control steps should be taken.

(b) Liquid addition. If liquid is to be added, it should be given a dielectric-breakdown test. The liquid to be added should be at least as warm as the liquid in the transformers. If a large amount of liquid is added, the transformer should remain deenergized for 12 hours or more to permit the escape of entrapped air bubbles. A desirable method is to add the liquid with the transformer tank under a vacuum. (Check the manufacturer’s instructions and IEEE C57.106 for further information.)

(12) *Internal inspection of dry-type transformers.* Enclosure covers of ventilated dry-type transformers should be removed carefully. Check for accumulations of dirt on windings and insulators, restriction to cooling airflow, discoloration caused

by overheating, and tracking and carbonization. Look for cracked or chipped insulators; loose insulators, clamps, or coil spacers; deterioration of barriers; and corroded or loose electrical connections.

(13) *Cleaning and other dry-type transformer requirements.* Dirt and dust should be removed from the windings with a vacuum cleaner. Compressed air may be used after vacuuming, but only if it is clean and dry and applied at a low pressure to avoid damage to windings. In particular, ventilating ducts and the top and bottom of the windings should be cleaned. The use of liquid cleaners should be employed only when it is known that they will not have a deteriorating effect on the insulation.

(a) Operation. Best service life will result if the windings are maintained above the ambient temperature level. For this reason, transformers operating in high humidity should be kept energized, if feasible. If a transformer is to be de-energized long enough for it to cool, special drying procedures may be required before the transformer is re-energized. Refer to the manufacturer's recommendations for drying procedures to be followed.

(b) Sealing. Sealing severe leaks, or opening and resealing the tanks of sealed dry-type transformers, requires special procedures and equipment. The manufacturer of the transformer, an experienced transformer repair facility, or a qualified electrical maintenance contractor should perform this work.

(c) Special procedures. In addition, special procedures covering drying out of the windings, and purging and refilling of the tank, may be required.

7-6. Transformer testing guidance.

All tests should meet the requirements of ANSI/IEEE CF57.12.90 for liquid-immersed transformers and IEEE (X7.12.91 for dry-type transformers. Expanded explanatory data for tests can also be found in NFPA 70B and "Electrical Equipment Testing and Maintenance."

7-7. Solid (winding) insulation tests.

Nondestructive tests for the dielectric properties of solid insulation include the insulation resistance test, the dielectric-absorption test, and the power factor test. High potential and induced potential tests can cause damage to the insulation. However, these tests do discover weakened insulation, and any damage is usually much less than that caused by an in-service failure. Insulation tests can be applied to dry-type transformers; however, the voltage impulse values should be lower than those used for liquid-immersed transformers. A transformer turns ratio test can identify trouble in transformer windings; its use in proof testing is generally limited to dry-type units.

a. Insulation resistance test. Routine insulation resistance tests on transformers are normally made at voltages given in table 3-4. Insulation resistance usually decreases somewhat with an increase in applied voltage. However, for a variation of two to one or three to one in the usual test voltage ranges, there is no appreciable effect on insulation resistance for equipment that is in good condition. Marked variations in insulation resistance for different values of voltage are usually due to the effects of dirt or moisture. The insulation resistance values for oil-filled transformers will vary due to humidity, size and type of transformer, temperature, and the value the test voltage applied.

(1) *Records.* A record should be made of all factors for comparison with previous and future test results. Temperature correction factors are indicated in table 7-2. To obtain the equivalent insulation resistance at 20 degrees C, multiply the insulation resistance reading in megohms by the appropriate correction factor. Values of winding insulation resistance may be affected by residual charges that are retained in the winding. For this reason, windings should be discharged to the frame until the discharge current reaches a negligible value. Ten minutes or more may be required to complete the discharge.

(2) *Insulation testers.* Resistance testers are available that indicate directly in ohms the resistance being measured. The power source necessary for operation of the tester may be a hand cranked generator, motor operated generator, or rectifier supplying a direct-current voltage for test purposes. For best results, the detailed instructions furnished with each of these instruments should be followed.

Table 7-2. Insulation resistance conversion factors to 20°C

Temperature (°C)	Transformer Oil	Transformer Dry
0	0.25	0.40
5	0.36	0.45
10	0.50	0.50
15	0.75	0.75
20	1.00	1.00
25	1.40	1.30
30	1.98	1.60
35	2.80	2.05
40	3.95	2.50
45	5.60	3.25
50	7.85	4.00
55	11.20	5.20
60	15.85	6.40
65	22.40	8.70
70	31.75	10.00
75	44.70	13.00
80	63.50	16.00

(3) *Test voltage.* An insulation test is not intended to be a destructive test. The test voltage used must be restricted to a value commensurate with apparatus voltage rating and condition of insulation being tested. This is particularly important in the case of small, low-voltage transformers or those units containing an excessive amount of moisture.

b. Polarization index (PI) test. A PI test or dielectric absorption test is a continuation of the insulation resistance test in which the voltage is applied for a longer period of time. For good insulation, the resistance values will increase with time. The polarization index is the ratio of the lo-minute to the l-minute readings. An index below 1 indicates poor insulation. An index between 1 and 2 indicates that the insulation is questionable. An index of a 2 and higher indicates good insulation.

c. Power factor test. The power factor of an insulation is a measure of the energy components of the charging current. The test indicates the power loss caused by leakage current through the insulation. The equipment to be tested should be disconnected and all bushings should be cleaned and dried. The test should be conducted when the relative humidity is below 70 percent and the temperature is above 32 degrees F (0 degrees C). On transformer tests, the power factor of each winding with respect to ground, and each winding with respect to its other winding, should be measured. Evaluation of the data obtained should be based on comparison of data with any previous tests on the same transformer or on test data from similar units.

d. High-potential test. A high potential test is a voltage applied across an insulation, at or above the direct-current equivalent of the 60-hertz operating crest voltage. The maximum direct-current test voltage for periodic testing between windings, and from winding to ground, should not exceed the original factory alternating-current test voltage. Good insulation will exhibit a gradually rising leakage current with an increase in test voltage. If the leakage current increases rapidly, the test should be halted because a breakdown of the insulation is indicated.

7-8. Transformer insulating liquids.

The insulating liquids used in liquid-immersed transformers not only provide insulation, but serve to transfer heat from the windings. The liquid must be kept free of contaminants and moisture, just as the air insulation of dry-type transformers must be kept clean and dry; otherwise, the medium's insulating ability is reduced.

a. Types of liquid. The insulation liquids used by most facilities will be mineral oil, in oil-insulated transformers, and fire-resistant petroleum (RTemp) or silicone fluids in less-flammable liquid-insulated transformers. Askarel or PCB units should have been removed, or be in the process of being removed, from most installations. Tetrachloroethylene (Wecosol) fluid used in nonflammable fluid-insulated transformers, can evaporate to produce toxic fluids and its use should not be an allowable option in facility design manuals/specifications.

b. Air and moisture are the major enemies of insulating liquids. The oxygen in the air will cause the formation of acids and sludge in the oil. Moisture, in as small an amount as 10 parts per million by volume, can reduce the dielectric strength of insulating oil to below its acceptable value. All containers and equipment used for handling insulating liquids must be clean. Equipment used with mineral oil should never be used with less-flammable liquids, as any mineral oil residue will change the less-flammable liquid's fire-point characteristics. Transformers should not be retrofilled with a different type of insulating liquid, as this can cause the transformer to malfunction. Likewise, great care must be used to ensure that any liquid used to "top off" a transformer is compatible in all respects with the liquid already in it. The best practice is to consult the transformer manufacturer or the manufacturer of the liquid intended to be used for topping off. In the following paragraphs, where no values are given, consult the manufacturer.

c. Sampling. Samples should never be taken from energized transformers, except by means of an external sampling valve. If the transformer has no external sampling valve, the unit must first be de-energized and a sample taken internally,

(1) *Obtaining the Liquid.* The methods of obtaining liquid samples are covered in ASTM D 923. Oil samples should be taken from the bottom of the transformer, while less-flammable liquid samples should be taken from the top. The samples should stand in tightly sealed containers for 24 hours prior to testing.

(2) *Sampling considerations.* The test validity is dependent upon the validity of the sample. Use clean, dry, glass containers with nonrubber wax-sealed stoppers to prevent leakage. Take samples when the oil is at least as warm or warmer than the surrounding air, and always on a clear windless day when the relative humidity does not exceed 70 percent. Run about one quart (one liter) of liquid through any supply valve to clean it thoroughly. Vent any sealed transformer which has a vacuum. Place the sample in a refrigerator's freezing compartment overnight. A cloudy sample indicates free water and another sample should be taken to determine whether the water was in the sample container or in the oil.

d. Type of tests. Annual, comprehensive, and dissolved oil-in-gas tests are made on liquid insulation. ANSI/IEEE C57.106 and ASTM D 117 cover acceptance, maintenance, and test requirements.

(1) *Annual tests.* Annual tests determine whether the insulating liquid is in satisfactory condition or whether more comprehensive tests should be made.

(a) Dielectric breakdown. The dielectric breakdown voltage test is covered in ASTM D 877. The minimum acceptable breakdown values are 22 kV for oil and 26 kV for RTemp and silicone.

(b) Acidity. The acidity test is covered in ASTM D 1534. This test indicates how much the oil has oxidized. The maximum permissible neutralization number is 0.4 for oil, 0.5 for RTemp, and 0.01 for silicone.

(c) Color. The color test is covered in ASTM D 1524. New oil is clear, while a dark oil indicates contamination. The maximum acceptable "color number" is 4 for oil and 1.5 for RTemp.

(2) *Comprehensive tests.* Comprehensive tests include a power factor test using an ASTM D 924 test cell, and an interfacial tension (IFT) test in accordance with ASTM D 971 or ASTM D 2285. A liquid at 20 degrees C, with a power factor as given in table 7-3, is considered satisfactory. If the value is above 0.5 percent investigate. If the value is above 2 percent, replace or recondition. The IFT will vary dependent upon the liquid used, but values below 40 dynes per centimeter for oil, 30 dynes per centimeter for RTemp, and 21 dynes per centimeter for silicone probably indicate that reconditioning is advisable.

Table 7-3. Satisfactory power factors

	Mineral oil	RTemp	Silicone
Power transformers	0.005	0.005	0.005
Distribution transformers	0.01	0.0 1	0.005

(3) *Dissolved gas-in-oil tests.* ASTM D 3612 covers this test which analyzes the combustible gas liberated by normal use of insulating liquid. The dissolved gases are extracted from an oil sample. A portion of the gases are then subjected to chromatographic analysis. This analysis determines the exact gases present and the amount of each. Different types of incipient faults have different patterns of gas evolution. With this test the nature of the problems can often be diagnosed, utilizing data from IEEE 104.

e. Reconditioning and replacement of insulating Liquids. If any of the tests indicate that an insulating liquid is not in satisfactory condition, it may be restored by reconditioning, reclaiming, or it can be completely replaced. Reconditioning is the removal of moisture and solid materials by mechanical means such as filter presses, centrifuges, or vacuum dehydrators. Reclaiming is the removal of acidic and colloidal contaminants, and products of oxidation, by chemical and absorbent means. These include processes involving Fuller's earth, either alone or in combination with other substances. Replacing the liquid involves draining, flushing, testing, and proper disposal of materials removed. It is recommended that these procedures be done by contract personnel who have the necessary experience and equipment.